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Manatū Ōhanga

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REC'D 15 OCT 2003
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CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 26 September 2002 with an application for Letters Patent number 521651 made by INVENSYS ENERGY SYSTEMS (NZ) LIMITED.

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Dated 1 October 2003.

Neville Harris

Neville Harris
Commissioner of Patents, Trade Marks and Designs

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Intellectual Property
Office of NZ

26 SEP 2002

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Patents Form No. 4 Our Ref: JI217733

Patents Act 1953

PROVISIONAL SPECIFICATION

BATTERY MANAGEMENT SYSTEM

We, **INVENSYS ENERGY SYSTEMS (NZ) LIMITED,** a New Zealand company, of 39 Princess Street, Christchurch 8004, New Zealand do hereby declare this invention to be described in the following statement:

PT0429102

BATTERY MANAGEMENT SYSTEM

The present invention relates to a battery management system.

On-line battery monitoring is becoming acceptable common practice within telecommunication power systems applications. A number of commercial products are currently available for such purposes. See for example E Gotaas & A Nettum; "Single Cell Battery Management Systems (BMS)"; Intelec 2000; Sept 10-14 2000; Phoenix; USA; Paper 36.2; or A Anbuky, P Pascoe & P Hunter; "Knowledge Based VRLA Battery Monitoring & Health Assessment"; Intelec 2000; Sept 10-14 2000; Phoenix; USA; Paper 36.1.

Known commercial products all present advantages over conventional intermittent or offline monitoring. The approach to monitoring is either based on centralised sensing and intelligence (see for example S Deshpando et al; "Intelligent Monitoring System Satisfies Customer Needs for Continuous Monitoring and Assurance on VRLA Batteries"; INTELEC, 1999) or distributed sensing and centralised intelligence organisation. Many of these products deal with a low level of information processing (e.g. smoothing and limit violation detection) while leaving the intelligent part to a human expert. With the advancement of microelectronic technology, local sensing and intelligence is becoming feasible allowing for distributed sensing and intelligence organisation. One further aspect that requires attention when it gets to the low energy batteries is the power required by the sensor to operate. Sensors are normally parasitic on the battery. Energy consumption becomes noticeable when dealing with low ampere-hour batteries.

The basic goals for an advanced battery management system are a) presenting timely information on battery reserved time upon mains failure, b) presenting timely information on battery remaining life, and c) maintaining safe battery operation (i.e. preserving battery life). These goals are either partially met by the central management unit or left to the human expert. The third goal of life preservation imposes the requirement of charge management and control. An appropriate hardware device would be required for interaction among a group of cells to facilitate individual cell current feeding and draining. An optimal solution should determine the internal status of each cell and provide a facility to individually optimise each cell's float charge. There will always be a trade-off between cost and the functionality that is provided by additional electronics. The proposed ASIC solution presented by Scott (N Scott; "A single Integrated Circuit Approach to Real Capacity Estimation and Life Management of

VRLA Batteries"; Intelec'01; Edinburgh International Conference Centre (EICC) UK; 14-18 Oct'01) satisfies some of the requirements. However, an optimal ASIC design will swing this equation in favour of functionality. An intelligent node should provide a hardware platform that will facilitate any battery test procedure, leaving future functional improvements to software upgrades.

A further known system is described in A Anbuky, Z Ma & S Sanders; "Distributed VRLA Battery Management Organisation with Provision for Embedded Internet Interface"; Intelec 2000; Sept 10-14 2000; Phoenix; USA; Paper 37.2.

Battery charge management involves both sensing and feeding in addition to the monitoring activities. The most effective region for life preservation within standby applications would be the float region. Both electrode voltage polarisation and cell equalisation need to be appropriately managed to be effective in reducing the stress on the battery cells. Here monitoring the cell full charge status and providing an ability to feed the low cell would be essential for the charge management role. Float current sensing would provide additional backup to the management activities.

A first aspect of the invention provides a battery management system including a sensing module; a feeding module; a control module coupled to the sensing module and the feeding module; and a common line coupled to both the sensing module and the feeding module and adapted for connection to a battery when in use, wherein the sensing module is configured to receive battery information from the common line and output a sensing signal to the control module in accordance with the battery information, wherein the control module is configured to receive the sensing signal from the sensing module and output a control signal in accordance with the battery information, and wherein the feeding module is configured to feed and/or drain a battery connected to the common line when in use in accordance with the control signal.

The first aspect of the invention recognises the fact that both sensing functions, and control functions (for example feed or drain of current for equalisation purposes) can both be performed via a common line. This minimises the number of parts required and lends itself to an embedded solution – that is, the sensing, feeding and control modules can be enclosed in a battery compartment..

The system may have only one common line, but in general a number of common lines will be provided. Typically at least two common lines are provided, each coupled to a respective end of a battery.

A second aspect of the invention provides a battery management system including a sensing module; a feeding module; and a control module coupled to the sensing module and the feeding module; wherein the sensing module is configured to receive battery information and output a sensing signal to the control module in accordance with the battery information, wherein the control module is configured to receive the sensing signal from the sensing module and output a control signal in accordance with the battery information, wherein the feeding module is configured to feed and/or drain a battery connected to the feeding module when in use in accordance with the control signal in order to perform equalisation of a string of serially connected batteries, and wherein the control module is configured to perform one or more additional battery monitoring or management tasks.

The second aspect of the invention provides a generic system capable of performing battery equalisation and also one or more other monitoring or management tasks. Examples include (but are not limited to) impedance testing or capacity testing.

An embodiment of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a battery network management system;

Figure 2 is a schematic diagram showing the architecture of a node controller;

Figure 3 is a schematic diagram showing a monitor and equalise interface unit (MEIU) in detail;

Figure 4 is a schematic diagram of a shunt interface unit (SIU);

Figure 5 is a schematic diagram illustrating a communication model for the system of Figure 1;

Figure 6 is a graph showing equalisation of a discharged cell;
Figure 7 is a graph showing equalisation of cells on float;

Figure 8(a) is a graph showing equalisation of Gates 25AH Cyclon cells with a high feed;

Figure 8(b) is a graph showing equalisation of Gates 25AH Cyclon cells with a low feed;

Figure 9(a) is a graph showing equalisation of Hawker 2HI275 cells with a low feed;

Figure 9(b) is a graph showing equalisation of Hawker 2HI275 cells with a high feed;

Figure 10(a) is a graph showing shunt temperature performance at low current;

Figure 10(b) is a graph showing shunt current performance at low current; and

Figure 11 is a cross-section through a group of cells with an embedded processor.

System Organisation

A battery management system 1 is organised in the manner shown by Figure 1. The system includes a number of nodes. Each node looks after a group of cells 3 and is managed by a single node controller 5. Each node also includes a Monitor and Equalise Interface Unit (MEIU) 4. One of the nodes (at the top of a string 2) also includes a Shunt Interface Unit (SIU) 7. A node including an SIU is referred to below as a "string node" and the other nodes are referred to below as "group nodes". The node controller 5 allows for interfacing to one or both of these interface units. This arrangement facilitates a generic controller with provision for variance at the interface level.

Each string of cells 2 is connected in parallel to a power bus 8. The nodes are connected to a battery node 11 via a CAN bus 9,10. The battery node 11 has two basic roles. A first role is to perform battery level management. A second role is to act as a gateway to a remote manager 13 via a WAN 12.

Node Architecture

The node design, as shown in Figure 2, is based on three main components. These are:

1. Node Controller 5
2. Node Interface 4
3. CAN Controller and Transceiver 6

The node controller 5 hosts all necessary software for driving the communication controller 6 and node interface 4 - that is, it hosts a sensing module 20, feeding module 21 and communication module 25. The node controller 5 also hosts the knowledge modules relevant to signal processing, monitoring and control - that is, it hosts a control module 22, storage buffer 23 and monitoring module 24. The Node Interface 4 is a plug-in unit that provides the essential hardware for the specific functionality. Here two types of interface unit will be demonstrated; the *monitor and equalise interface unit* (MEIU) 4 and the *shunt interface unit* (SIU) 7. The communication controller 6 provides the necessary hardware and protocol software for facilitating standard communication among the acting nodes. The arrangement facilitates generic node hardware with a flexibility of introducing variance for the node interface or node monitoring, control and communication software.

Each battery string 2 is partitioned into a number of six-cell groups 3. Other arrangements could also be used. However, this size of cell grouping has been selected for the following reasons.

1. Provides sufficient number of cells for inter-cell comparison.
2. Formulates full, half and a quarter of the 12V, 24V and 48V strings respectively. The last two are commonly used for telecommunication applications.
3. The 12V mono-bloc is a typical six-cell unit. The solution would be a potential battery-embedded solution.

The node controller software contains components that handle the monitoring, control and communication activities. Any of these components could be upgraded or replaced when a new version or release is in place.

Node Interface Unit

Two types of interface units have been used here. These are a) the monitor and equalise interface unit (MEIU) 4 and b) the shunt interface unit (SIU) 7. The MEIU 4 facilitates cell data acquisition for the group that is being monitored. Cell voltages and group temperature are available here. It also facilitates energy routing from the group into the low cell when dealing with group equalisation. The unit operates through using a pair of sense lines 42,43 to feed a cell at a low rate. The rate of equalise is influenced by the size of battery and may be managed through the micro-controllers embedded PWM control.

Figure 3 shows the conceptual arrangement of the MEIU. A DC-DC converter 31 converts DC power at a group (or bus) voltage level into a cell voltage level. The converter 31 is connected to a pair of bus voltage lines 47,48. This facilitates feeding from a string of cells 2 into a low cell. The converter 31 is also connected to a pair of group voltage lines 49,50 via diodes 40,41. This facilitates feeding from a group 3 into a low cell. Feeding in the reverse direction is also possible when dealing with a high cell. The average feeding current could be made suitable for the targeted electronics and wiring. A given minimum however should be maintained that is relevant to the battery to be dealt with. Feeding of more than 100mA could be considered reasonable for a good range of battery capacities.

The second sub-unit within the MEIU is a multiplexing unit 30. This sub-unit has two basic modes of operation. These are a) sense mode and b) feed/drain mode. The sense mode selects a cell that is addressed by a cell selector 51 and connects a pair of output sense/feed lines 45 (each sense/feed line 45 being connected to one electrode of the selected cell) and connects them to a pair of input sense/feed lines 42,43. Input sense/feed line 43 includes a shunt resistor 44. When in sense mode, a pair of voltage sense lines (not labelled) and a current sense line (not labelled) are each connected to an analogue-to-digital converter (not shown) in the node controller 5 for voltage and current measurement. The feed/drain mode connects the selected cell to the DC-DC converter 31. The rate of feed is controlled by a PWM signal on PWM feed line 47 and the rate of drain is controlled by a PWM signal on PWM drain line 46. When in feed/drain mode, current and/or voltage measurements may continue to be made on the selected cell via the current/voltage sense lines.

The node interface unit could also be utilised for feeding special perturbations for testing the cell's charge status (i.e. fully charged or not). This would benefit from interpreting the cell

behaviour around full charge. This is an important feature in managing the battery at float. It would also facilitate testing of the cell health condition without the need for an external load.

Equalisation software in the node controller 5 activates a periodic voltage scan for all cells in the group, works out the lowest cell that requires equalisation and activates the feed until the cell is no longer the lowest among the group.

The shunt interface unit (SIU) 7 senses the string current, as shown in Figure 4. It acquires both the voltage and the differential temperature across the shunt terminal. The SIU 7 works out the string current. This caters for the full range of battery current including the float current.

Communication

The system architecture is based on three logical nodes shown in Figure 5. These are the group node, the string node and the battery node 11. The group-node looks after a sub-string group 3, utilising a monitor and equalise interface unit (MEIU). The string node looks after a top sub-string group as well as a string 2. This node is physically the same as the group node with the addition of the SIU. The battery node 11 is the network gateway. It provides the access to each of the string or group nodes. It also provides longer term buffering to network information and data. The battery node 11 node also provides a time reference to all network nodes. Enabling or disabling of each of the messages within the system could also be accessed through the battery node 11.

The node communication is based on a CAN bus 9,10. The battery node 11 acts as a gateway to the site and allows remote management. This node communicates with the battery local network using a CAN controller. It also communicates with a management wide area network 12 using the TCP/IP protocol over an Ethernet bus. The message structure has been organised to cater for key monitoring and control activities within the group relevant to both data and information messages. The message format caters for personalising the string allowing for group information to be visible by the associated string nodes and the battery node only.

The strategy for communication is to communicate commands, status and data. The battery node 11 has the authority to enable or disable the individual messages within the group or

the string nodes as shown in Figure 5. The group node 11 performs all monitoring and control locally. The relevant data is buffered and time stamped when significant changes take place. These changes are sent to the string and battery nodes as the changes take place or as requested. The group and string nodes also have the ability to send the short-term history to the battery node 11 when the associated buffer is full or upon request.

Node Applications

1. Cell equalisation

A software module for equalising a group of cells has been implemented. The software senses the voltage of each cell within the group, selects the lowest cell and boosts it until it reaches the average cell voltage. The process is repeated until all cells are equalised. Figures 6 to 9 show different test cases for group equalisation.

The case presented in Figure 6 shows that the node pulled the low cell up to within the group and then worked on the group to equalise them. Pulling the cell up took about 20 minutes. This is due to the amount of charge that the cell required as it was partially discharged. A cell voltage of around 2.13V indicates this. The group has eventually merged together around 2.27V.

Figure 7 shows a group of cells that are on float charge but are not equalised. The equalisation process took approximately one minute. Most of the float management of standby batteries will follow the case presented by Figure 7. Here, the equalisation process is assumed to be active all the time.

Figures 8(a) and 8(b) show the influence of changing the feed rate. The recovery of the cell in Figure 8(a) is appreciably faster than that of Figure 8(b). This is due to the feed being significantly greater in the case of Figure 8(a).

Figures 9(a) and 9(b) demonstrate equalisation of six Hawker 2HI275 cells. One cell has been discharged for two minutes at a 10A rate. Figure 9(a) shows the cell recovery that has taken place after approximately 3 hours of implementing the equalisation algorithm. At a high feed rate the recovery is much quicker as shown in Figure 9(b).

2. Intelligent Shunt Performance

The shunt interface unit 7 is designed to support the shunt in providing a wide range of string current measurement. The intention is to extend the range of normal current measurement presented by the shunt to cover the low current requirements needed by the float region. The shunt interface unit 7 acquires the shunt differential voltage and differential temperature. The string node controller utilises these values for calculating the string current. The electronic interface accounts for the necessary signal amplification in catering for the full current operational range.

Due to the wide range of current commonly encountered in standby applications, accurately measuring the float current of a battery string is a difficult task. A typical battery string may have charge and discharge currents of hundreds of amperes while the float current may be measured in tens to hundreds of milli-amperes. The measuring device must be able to pass the full load or charge current with minimal voltage drop. A typical 500A - 50mV current shunt has a resistance of 100 micro-ohms. 10mA of float current will produce 1 microvolt. While this may be amplified to a measurable level with a carefully designed high gain amplifier, thermal effects can notably influence measurement accuracy. The use of chopper stabilised operational amplifiers can significantly reduce amplifier drift and offset errors to acceptable levels however careful analysis of the actual measured signal must also be made.

As a shunt's measuring-element (such as manganin) is normally connected to copper sense wires (or copper printed circuit board tracks), a thermocouple is formed where the dissimilar metals meet. The temperature coefficient for a manganin/copper thermocouple is approximately 1.5 microvolts per degree Celsius. The signal-amplifier inputs sees the sum of the voltage developed across the shunt plus the two thermocouple voltages, i.e. $V_{Cu/(Cu\text{-}Mn)}$ + I_{Load} x R_{Shunt} + $V_{(Cu\text{-}Mn)/Cu}$. If both ends of the shunt are at the same temperature, the thermocouple voltages will cancel. However, less than one-degree centigrade difference in temperature between the measuring terminals of the shunt will cause an offset in the measured voltage (current).

Through measuring the temperature of the shunt connection points, compensation may be made for the thermocouple effects at the connection junctions. Figure 10 shows the temperature of the shunt's two-sense connections. The difference between the two

temperatures is used to compensate the float current measurement. The test presented in Figure (10) corresponds to no current flowing through the shunt.

Figures 1 to 5 describe an organisation for battery management. The organisation is based on a generic battery node. The node facilitates hardware for sensing, feeding and draining the cells of a battery. The storage resources provide room for algorithms that handle both monitoring and control. Charge control is managed through energy sharing among the group. The approach utilises the sense line for low cell feeding or draining. This encourages battery embedded electronics. The cell charge feeding and draining approach could facilitate battery remote testing, thus allowing for investigation of both battery charge and health without sacrificing the system integrity.

An embedded electronics solution is shown in Figure 11. A 12V mono-bloc 60 has six cells. The six cells are enclosed in a cell compartment bounded by a base 70, side walls 71,72, upper wall 73, and a pair of front/rear walls (not shown). The cell compartment is further sub-divided into six cell sub-compartments, each containing a battery chemical compartment 61 containing electrolyte, and a pair of electrodes 62,63. A valve 80 is provided in the upper wall for each compartment. The electrodes are connected in series and external ports 64,65 provide connection to the cells.

An electronics compartment is bounded by side walls 75,76, wall 73, wall 77 and a pair of front/rear walls (not shown). An electronics package 82 (containing MEIU 4, node controller 5 and communications controller 6) is housed in the electronics compartment and has output feed/sense lines 81 connected to the six electrodes 71, and a communications and external supply line 83.

While the present invention has been illustrated by the description of the embodiments thereof, and while the embodiments have been described in detail, it is not the intention of the Applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative apparatus and method, and illustrative examples shown and

described. Accordingly, departures may be made from such details without departure from the spirit or scope of the Applicant's general inventive concept.

It is therefore intended by the appended claims to cover any and all such applications, modifications and embodiments within the scope of the present invention.

CLAIMS

1. A battery management system including a sensing module; a feeding module; a control module coupled to the sensing module and the feeding module; and a common line coupled to both the sensing module and the feeding module and adapted for connection to a battery when in use, wherein the sensing module is configured to receive battery information from the common line and output a sensing signal to the control module in accordance with the battery information, wherein the control module is configured to receive the sensing signal from the sensing module and output a control signal in accordance with the battery information, and wherein the feeding module is configured to feed and/or drain a battery connected to the common line when in use in accordance with the control signal.

2. A system according to any one of the preceding claims including a multiplexer for selectively connecting a plurality of batteries to the common line.

3. A battery management system including a sensing module; a feeding module; and a control module coupled to the sensing module and the feeding module; wherein the sensing module is configured to receive battery information and output a sensing signal to the control module in accordance with the battery information, wherein the control module is configured to receive the sensing signal from the sensing module and output a control signal in accordance with the battery information, wherein the feeding module is configured to feed and/or drain a battery connected to the feeding module when in use in accordance with the control signal in order to perform equalisation of a string of serially connected batteries, and wherein the control module is configured to perform one or more additional battery monitoring or management tasks.

4. A system according to claim 3 wherein the one or more additional battery monitoring or management tasks include impedance testing.

5. A system according to claim 3 or 4 wherein the one or more additional battery monitoring or management tasks include capacity testing.

6. A system according to any one of the preceding claims wherein the sensing, feeding and control modules are enclosed in a battery compartment.

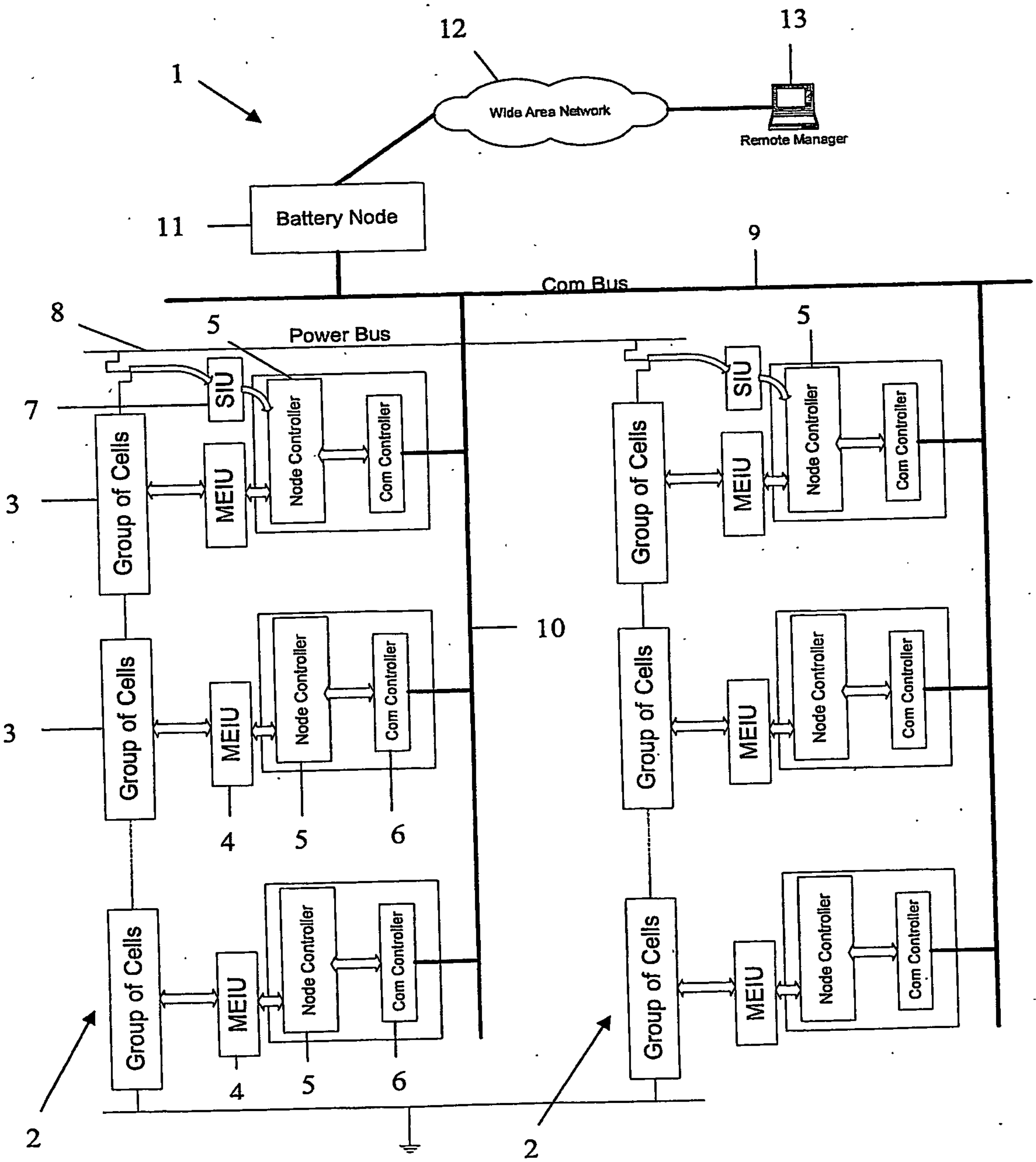
7. A system according to any one of the preceding claims including a multiplexer for selectively connecting a plurality of batteries to the sensing module and/or the feeding module.

INVENSYS ENERGY SYSTEMS (NZ) LIMITED
By their Attorneys
BALDWIN SHELSTON WATERS

Abstract

Battery Management System

A battery management architecture with an organisation based on a generic node. The node contributes to both the monitoring and control activities that satisfy low-level requirements for battery management. The technology implemented here is based on advanced general-purpose micro-controllers that benefit from both high degrees of integration and low power consumption. The solution could potentially be embedded within the battery, allowing for dynamic changes to the monitoring and control role through the node's software. Battery group equalisation is used here as an example for monitoring and control. Energy available among the group of cells is shared in a manner that allows for on-line and continuous equalisation of the cell voltages. Energy sharing is performed at a rate suitable for both requirements of a) charging process, and b) hardware optimisation. Low power electronics have been employed here for energy routing through the sense line. This approach benefits both rapid recharge and safe float boost. Depending on the controller resources, the generic node could accommodate processing modules that support the key monitoring functionality. This will substantially reduce the levels of supervisory and management computation. Furthermore, the organisation allows for in-system programming, which facilitates remote updates to the node knowledge.



12
13
1
Wide Area Network
Remote Manager
11
Battery Node
9
Com Bus
8
5
Power Bus
5
7
SIU
Node Controller
Com Controller
SIU
Node Controller
Com Controller
3
Group of Cells
MEIU
Group of Cells
MEIU
10
3
Group of Cells
MEIU
Node Controller
Com Controller
Group of Cells
MEIU
Node Controller
Com Controller
4
5
6
Group of Cells
MEIU
Node Controller
Com Controller
Group of Cells
MEIU
Node Controller
Com Controller
4
5
6
2
2

Figure 1

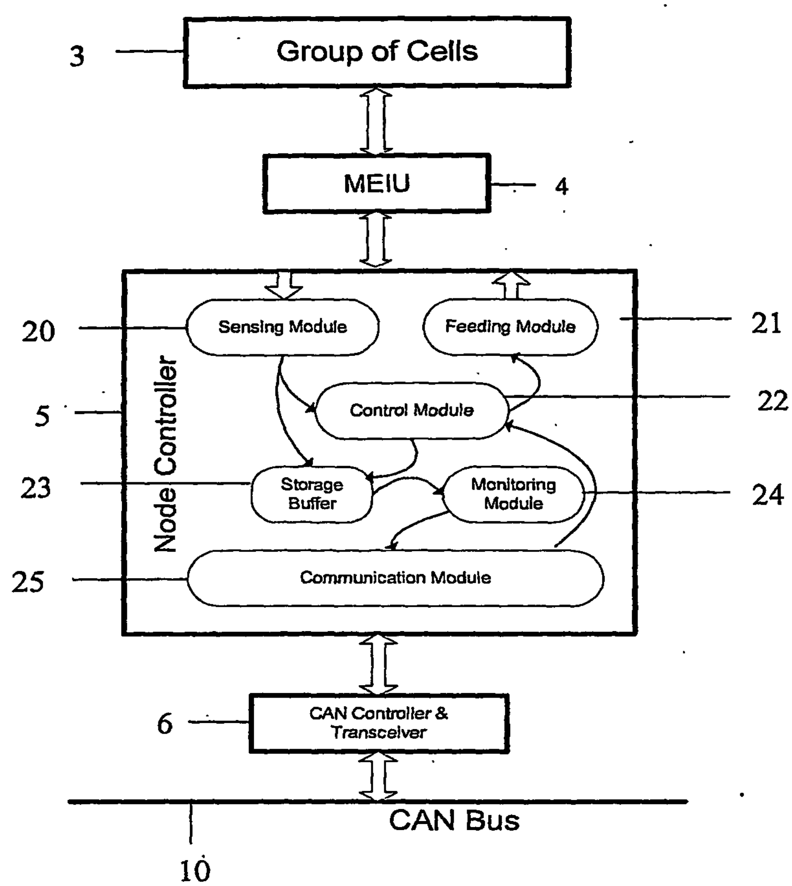
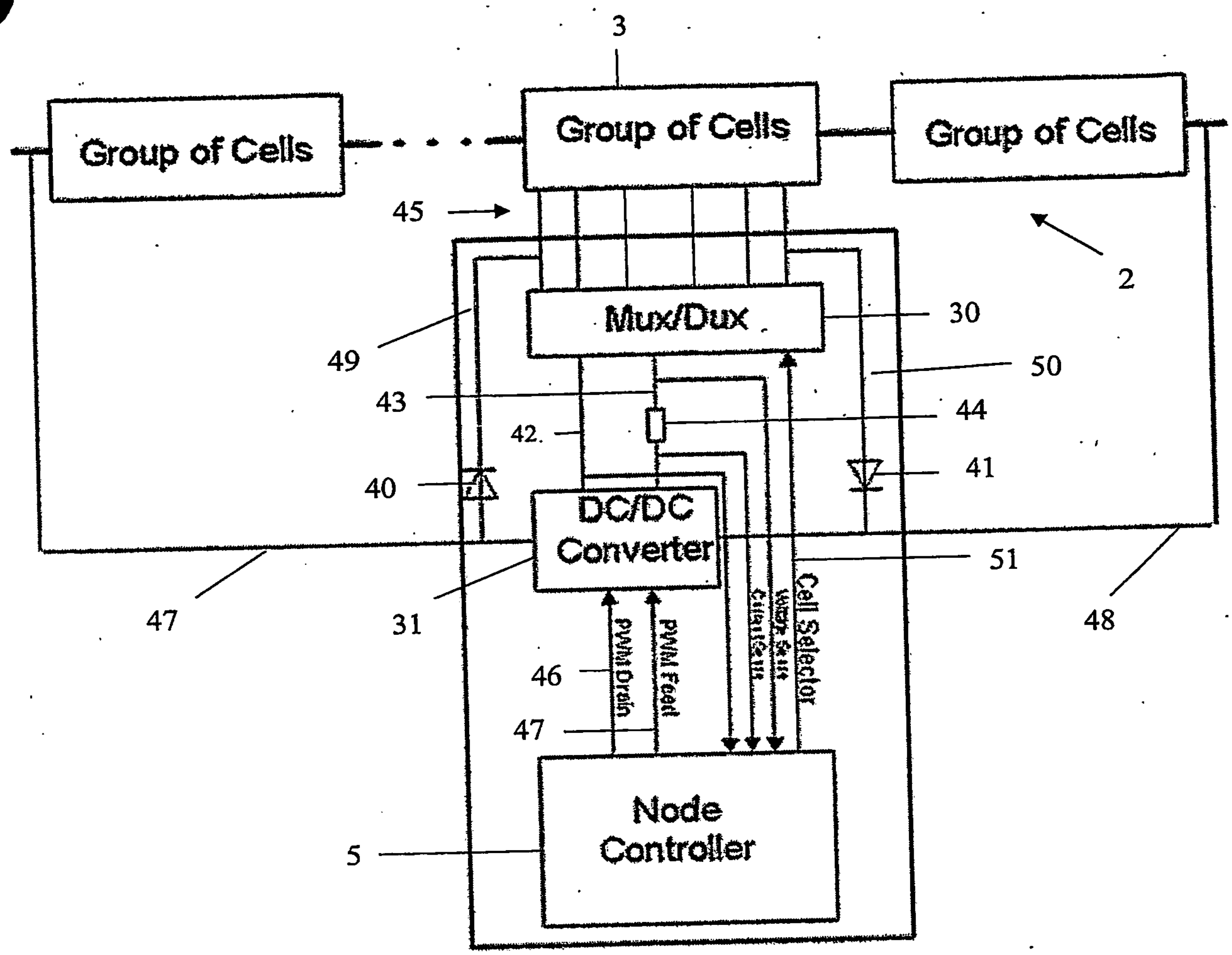

3
Group of Cells
MEIU
4
Node Controller
20
Sensing Module
Feeding Module
21
Control Module
22
5
23
Storage Buffer
Monitoring Module
24
25
Communication Module
6
CAN Controller & Transceiver
CAN Bus
10

Figure 2



3
Group of Cells
Group of Cells
Group of Cells
45
2
Mux/Dux
30
49
50
43
44
42.
40
41
DC/DC Converter
51
47
31
48
PWM Drain
PWM Feed
Cell Selector
46
47
Node Controller
5

Figure 3

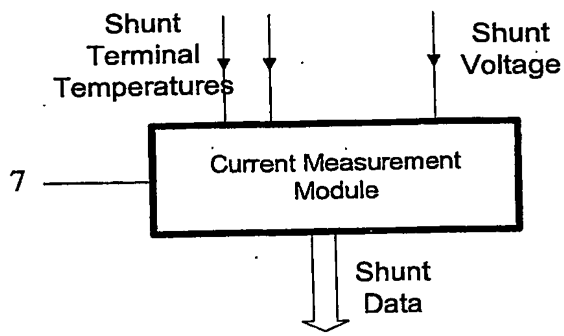


Figure 4

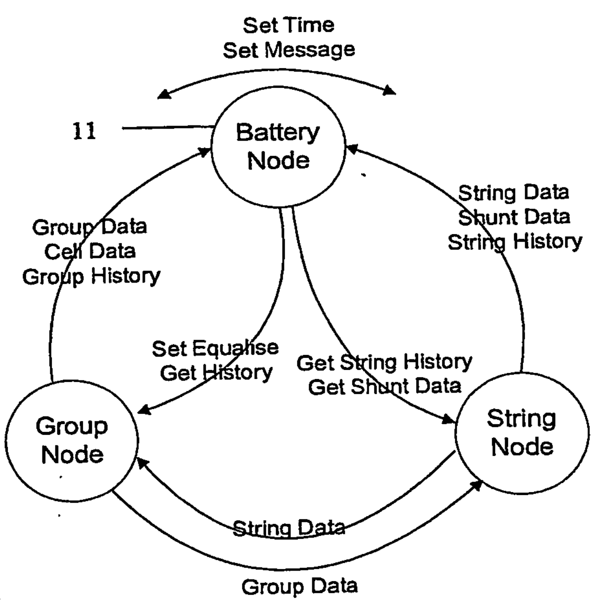


Figure 5

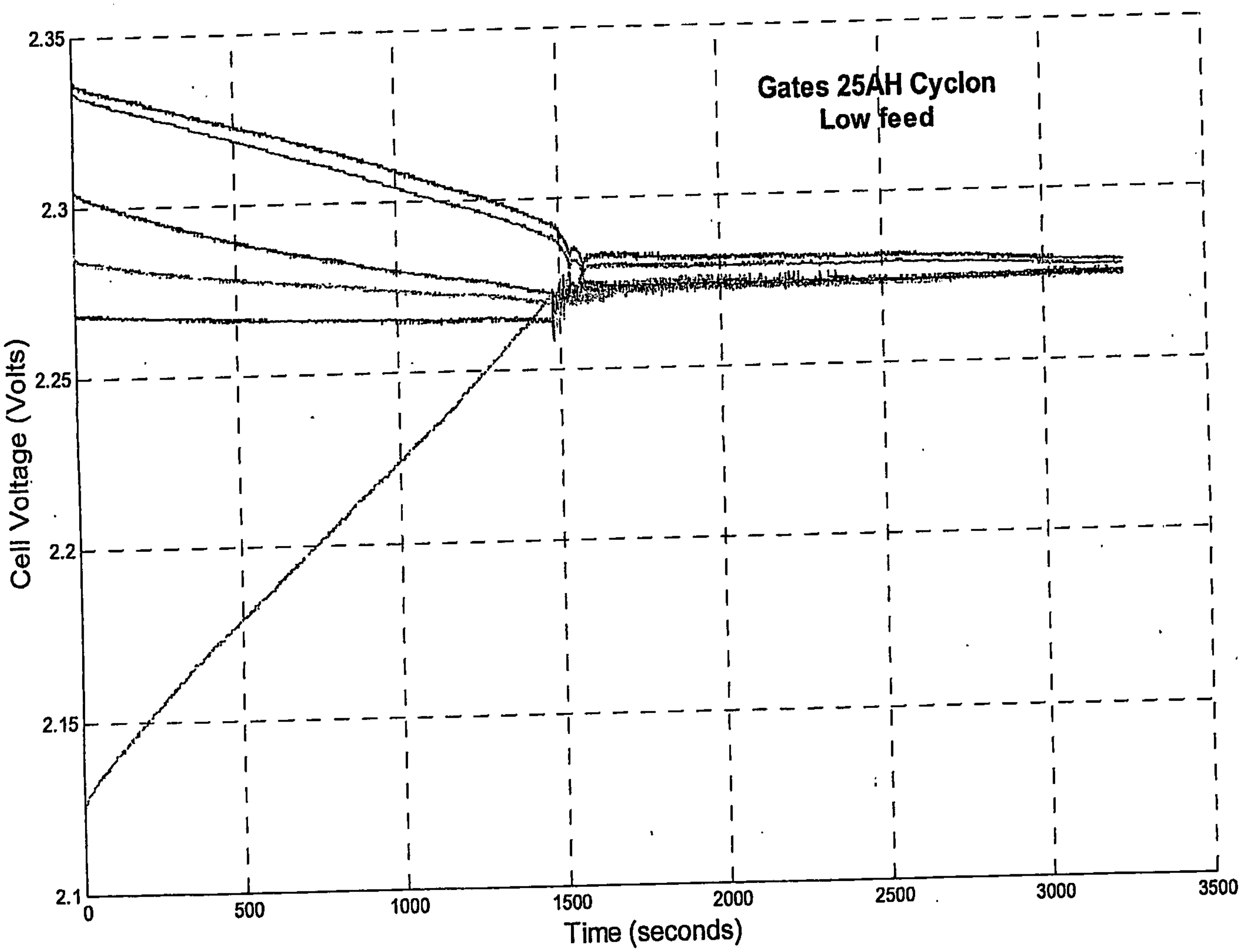

Gates 25AH Cyclon
Low feed
2.35
2.3
2.25
2.2
2.15
2.1
Cell Voltage (Volts)
0
500
1000
1500
2000
2500
3000
3500
Time (seconds)

Figure 6

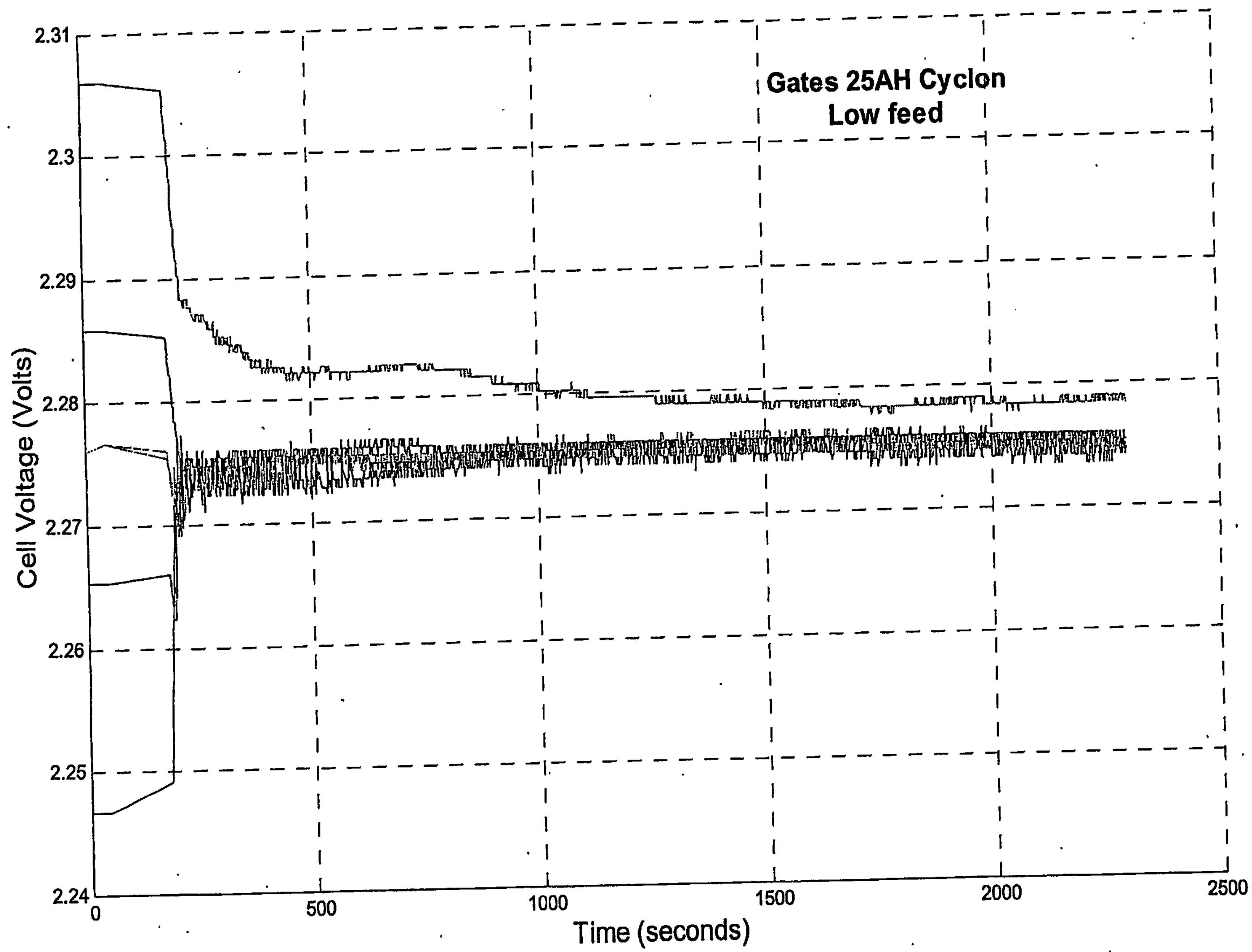
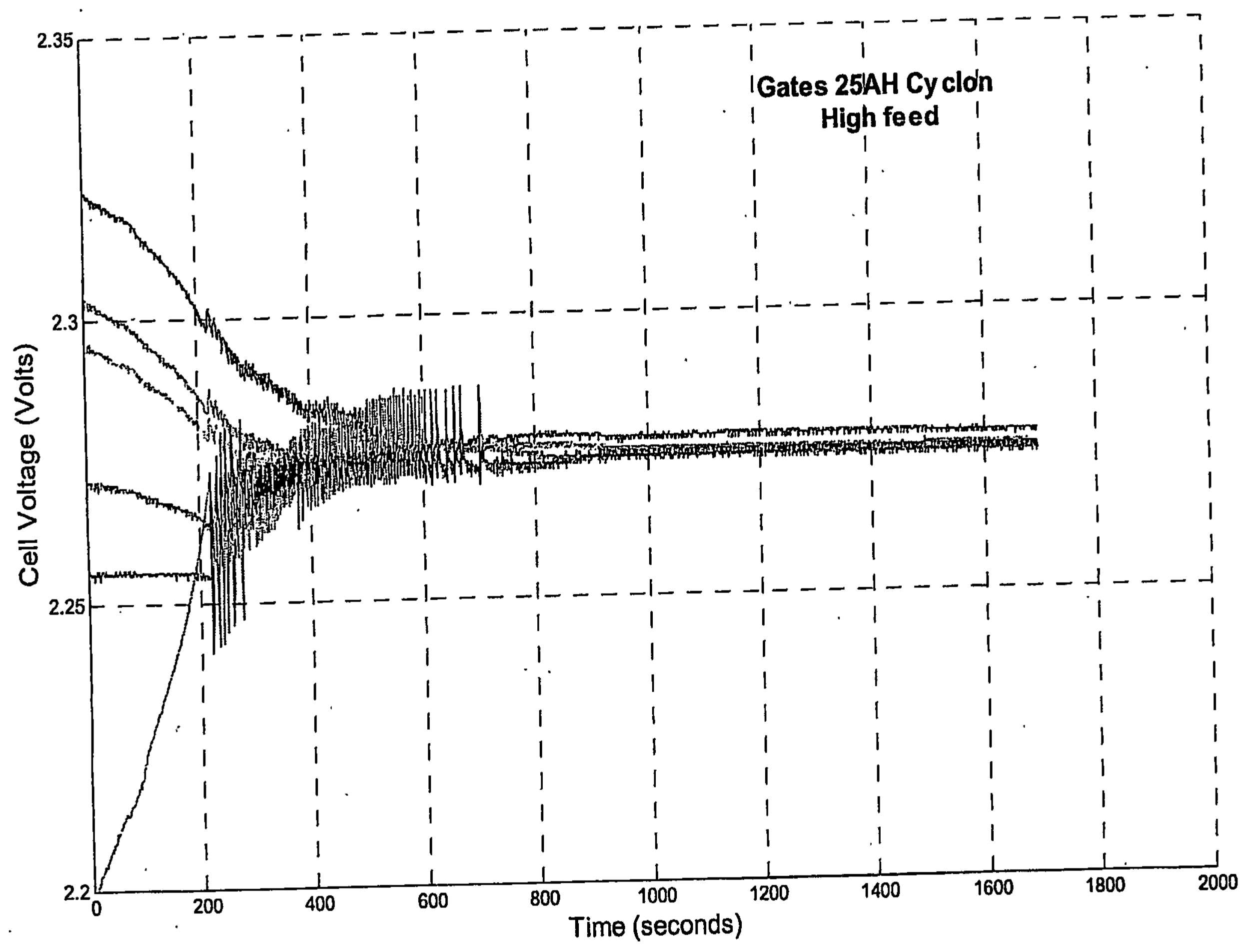

Gates 25AH Cyclon
Low feed
Cell Voltage (Volts)
2.31
2.3
2.29
2.28
2.27
2.26
2.25
2.24
0
500
1000
1500
2000
2500
Time (seconds)

Figure 7



Gates 25AH Cy clon
High feed
2.35
2.3
2.25
2.2
Cell Voltage (Volts)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (seconds)

Figure 8 (a)

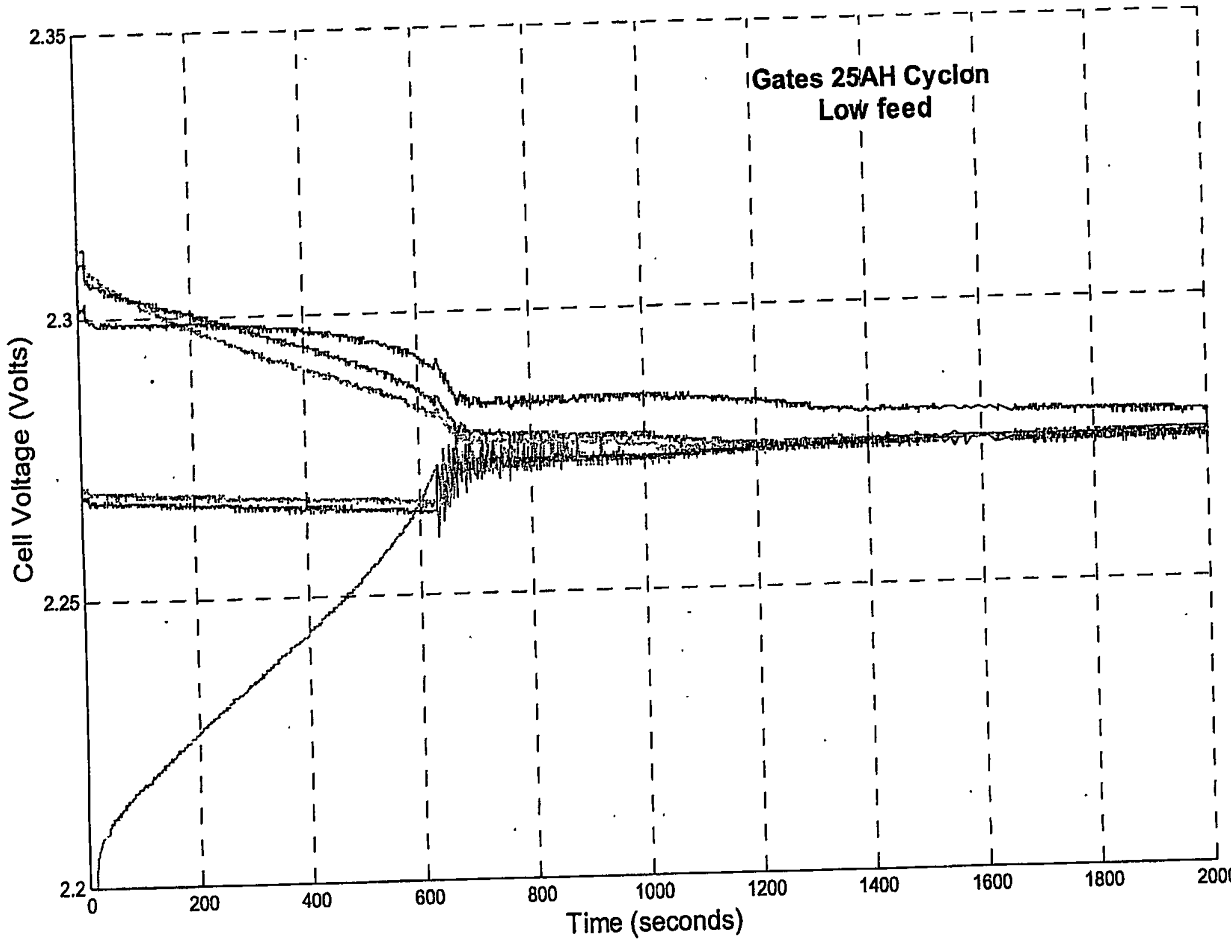

Gates 25AH Cyclon
Low feed
Cell Voltage (Volts)
2.35
2.3
2.25
2.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (seconds)

Figure 8 (b)

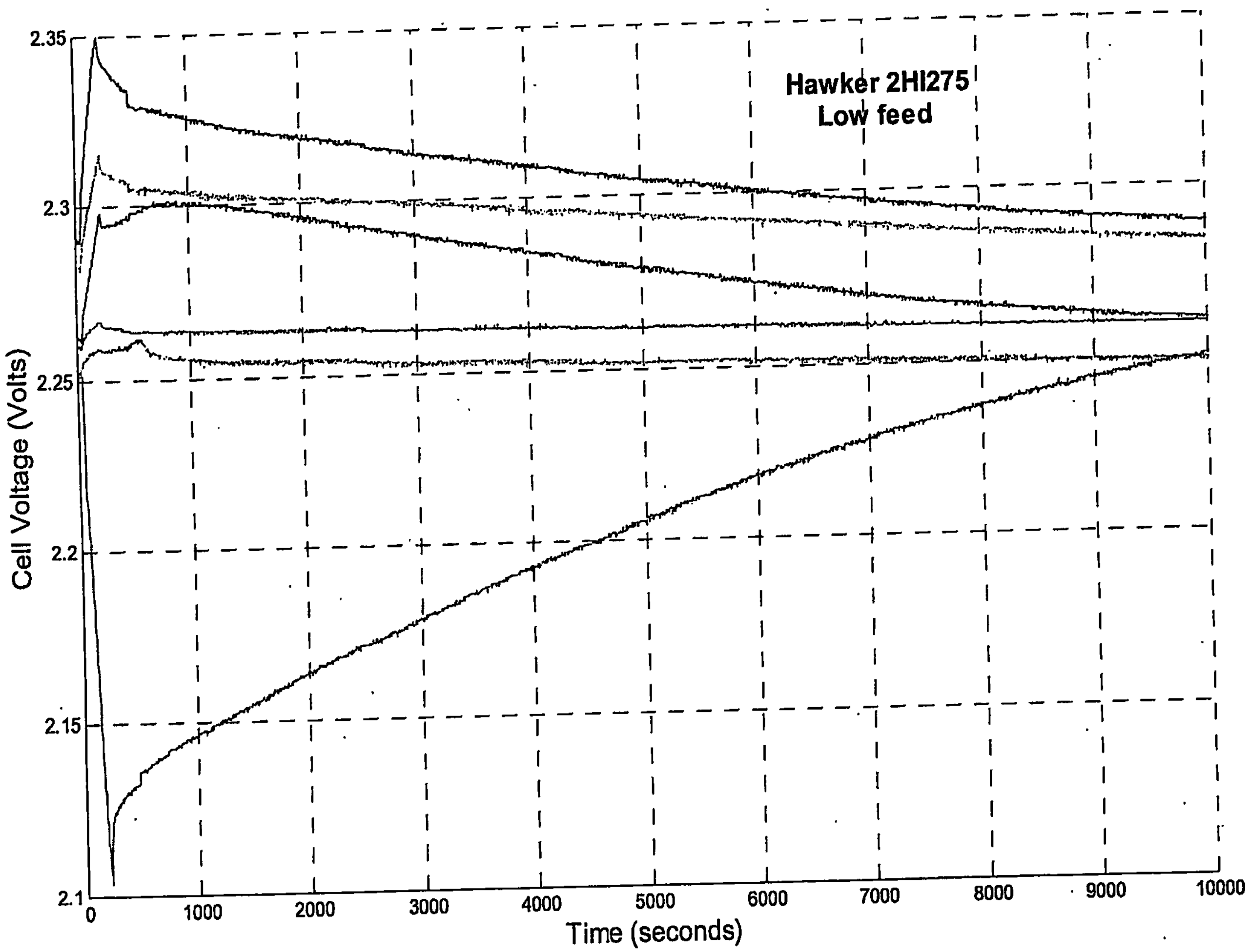

Hawker 2HI275
Low feed
Cell Voltage (Volts)
2.35
2.3
2.25
2.2
2.15
2.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (seconds)

Figure 9 (a)

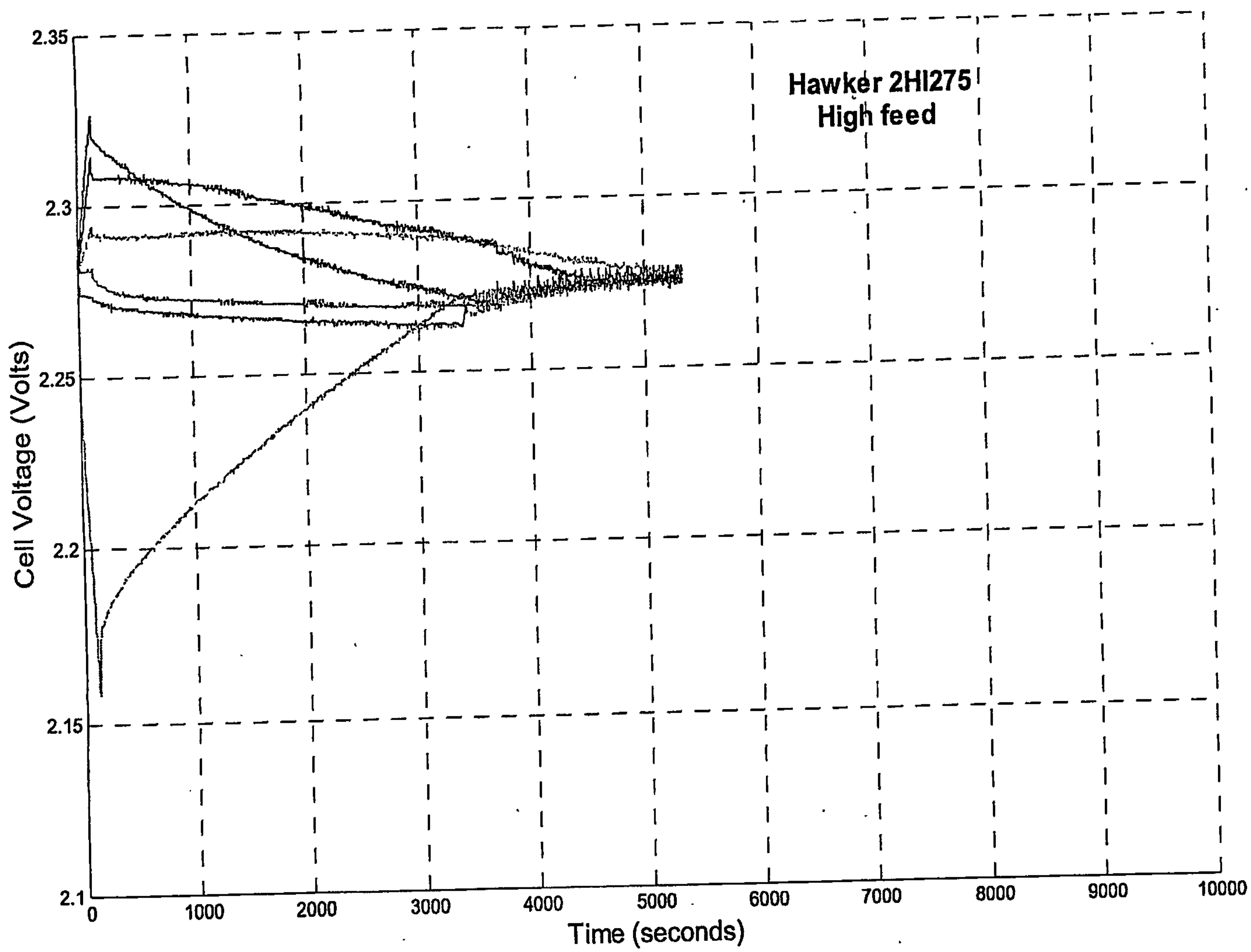

Hawker 2HI275
High feed
Cell Voltage (Volts)
2.35
2.3
2.25
2.2
2.15
2.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (seconds)

Figure 9(b)

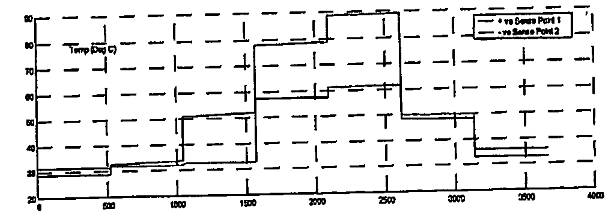


Figure 10 (a)

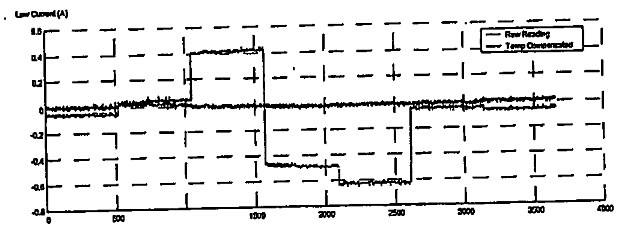


Figure 10 (b)

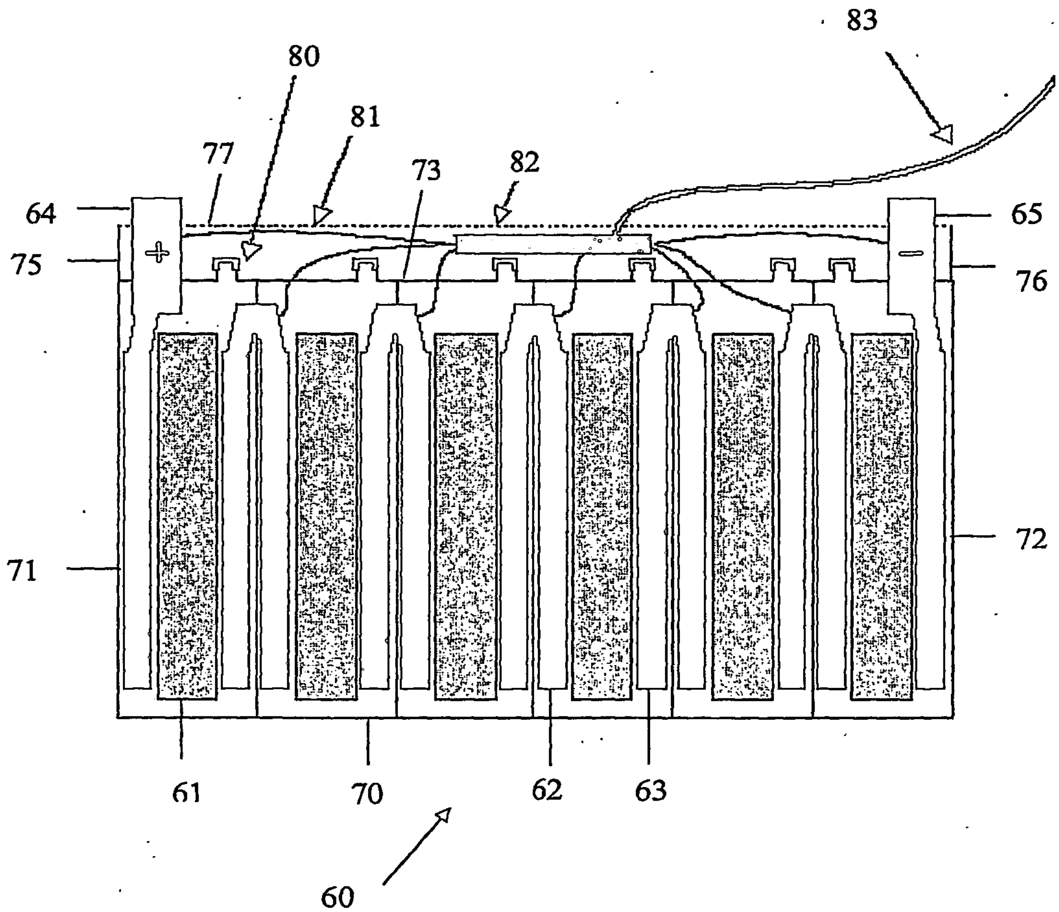


Figure 11

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